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BEFORE THE

Federal Communications Commission

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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF SECRETARY

In the Matter of	)	
	)	
Preparation for International Telecommunications Union World Radiocommunication Conferences	)))	IC Docket No. 94-31

TO: The Commission

REPLY COMMENTS OF AEROSPACE AND FLIGHT TEST RADIO COORDINATING COUNCIL

Aerospace and Flight Test Radio Coordinating Council ("AFTRCC"), by its attorneys, hereby replies to certain of the opening comments filed in the above-captioned proceeding.

I.

INTRODUCTION

AFTRCC is an association of the leading U.S. manufacturers of aircraft, space vehicles, and their major components. Given its members' role in aerospace development and testing programs, AFTRCC serves as the FCC-recognized non-Government advisory committee for coordination of flight test frequencies shared with Government users.

Related to its day-to-day coordination activities is AFTRCC's long and active involvement in spectrum policy issues. AFTRCC has been a frequent commenter in FCC rulemakings. More significantly,

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AFTRCC has initiated private sector efforts which led to the allocation of radio spectrum for flight test telemetry. This includes notably its 1957 initiative which led to the allocation of the 1.4 - 1.5 GHz spectrum for telemetry, a portion of which band is discussed herein.[1] More recently, AFTRCC successfully petitioned for rule changes which eliminated potential regulatory handicaps to the global competitiveness of the nascent United States commercial space launch industry.[2] AFTRCC participated actively in the Commission's preparations for the 1992 World Administrative Radio Conference ("WARC") with particular focus on the spectrum set aside for flight testing. In short, AFTRCC is uniquely positioned to comment on the implications of proposals which seek a reallocation of spectrum allocated in the United States for flight test telemetry.

II.

DISCUSSION

In its opening comments American Mobile Satellite Corporation ("AMSC") argues that a portion of the flight test band, namely 1492 - 1525 MHz, should be made available domestically for mobile satellite purposes. In support AMSC references its comments to the National Telecommunications and Information Administration ("NTIA")

1/ See Part 2 - Frequency Allocations and Radio Treaty Matters; General Rules and Regulations, F.R. Doc. 58-7571, Sept. 17, 1958 at 7177.

2/ Amendment of the Frequency Allocation and Aviation Services Rules (Parts 2 and 87) to Provide Frequencies for Use by Commercial Space Launch Vehicles, 5 FCC Rcd 493 (1990).

in connection with that agency's Preliminary Spectrum Reallocation Report. AMSC goes on to contend that its comments "demonstrate" that MSS can share spectrum with flight testing -- although "it is likely to take one more year... before a definitive agreement can be reached on sharing principles." Id at 14. Based on this AMSC suggests that the United states seek a change in the international table so as to allow MSS in this band within the U.S.

There is no merit to AMSC's assertions.

Preliminarily it should be noted that AMSC is among the last of those which should be heard to argue for additional spectrum. AMSC was licensed by the Commission nearly five years ago, in August of 1989. Memorandum Opinion and Order, 4 FCC Rcd 6041. It has still not launched its first satellite. Moreover, unlike the five low earth orbit applicants, who will be required to share the spectrum allocated for LEO MSS, AMSC has enjoyed the unique luxury of having an exclusive U.S. license for a very substantial amount of spectrum (1544 - 1558.5/1645.5 - 1660.0 MHz).

Despite this AMSC beats the drum for more. Indeed, the ink was hardly dry on the Final Acts from the 1992 World Administrative Radio Conference -- a WARC which allocated 1525 - 1530 MHz for geostationary MSS -- before AMSC was back before the Commission seeking 10 MHz more (1515 - 1525 MHz). The Commission quite properly rejected that request on the grounds that MSS would interfere with flight testing and be contrary to the United States position just adopted at the WARC. See Notice of Proposed

Rulemaking and Tentative Decision in ET Docket No. 92-28, 7 FCC Rcd 6414 at n. 15 (1992).

More recently, AMSC attempted to include itself among the recipients of spectrum for Big LEOs. The Commission's proposed service rules reject that proposal as well. See Notice of Proposed Rulemaking in CC Docket No. 92-166 (FCC 94-11, released February 18, 1994) at paras. 20-22.[3/]

For better or for worse AMSC has proposed a technology and a system configuration which has become outmoded, inefficient and overpriced. In the five years since AMSC first got its license, low earth orbit technology has surpassed that for GEOs: Big LEO system coverage, system power, and subscriber savings are superior to those of AMSC. With spectrum increasingly scarce, it makes no sense to throw additional allocations at a system which is not the most efficient.

With respect to AMSC's predictions about sharing with flight testing, AFTRCC need only observe that this is a view which appears confined to AMSC alone. A recent study of this issue tentatively concludes that "co-frequency, co-coverage sharing may not be feasible", and that "co-frequency, non-coverage operation may be

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3/ If this were not enough, AMSC has pending before the Commission an application to use the bands 1530 - 1544 and 1631.5 - 1645.5 MHz, as well as a request by a newly-formed subsidiary, Personal Communications Satellite Corporation, for allocation of the bands 1970 - 1990 and 2160 - 2180 MHz for MSS.

very limited......[4] Accordingly, no weight should be accorded this argument.

III.

CONCLUSION

There continues to be no basis for acceding to AMSC's requests. United States preparations for WRC-95 (or WRC-97) should proceed unencumbered by proposals contrary to the United States position on the L-band adopted less than two years ago.

Respectfully submitted,

AEROSPACE & FLIGHT TEST
RADIO COORDINATING COUNCIL

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[4] Summary of Activities in the ITU Bureau of Radiocommunications Working Parties and Task Groups Concerning the Sharing of Aeronautical Mobile Telemetry Systems with the Satellite Broadcasting Service (Sound) and the Mobile Satellite Service in the Frequency Band 1452 to 1492 MHz, 2d page. This paper and its ITU-related attachments was submitted recently to Informal Working Group 3 of the FCC's Industry Advisory Committee for WRC-95 preparations. A copy is supplied as Attachment A hereto. The conclusions referenced above were made in the context of flight test sharing with Broadcast Satellite Sound (1452 - 1492 MHz). However, the Report observes that the "sharing situation [with MSS] is very similar to that with the (BSS(s))". Id.

ATTACHMENT A

SUMMARY OF ACTIVITIES IN THE ITU BUREAU OF RADIOCOMMUNICATIONS WORKING PARTIES AND TASK GROUPS CONCERNING THE SHARING OF AERONAUTICAL MOBILE TELEMETRY SYSTEMS WITH THE SATELLITE BROADCASTING SERVICE(SOUND) AND THE MOBILE SATELLITE SERVICE IN THE FREQUENCY BAND 1452 TO 1525 MHZ

United States of America

At the World Administrative Radio Conference (WARC) 1992, allocations were made for the Broadcasting Satellite (Sound)(BSS(S)) and the Broadcasting (Sound)(BS(S)) services in the band 1452-1492 MHz and to the Mobile Satellite(MSS) service in Region 2 in the band 1492-1525 MHz. These bands are shared with the Fixed(FS) and Mobile(MS) services. Existing aeronautical mobile telemetry systems are used in these bands by a number of nations, particularly in the USA. Studies have been made with respect to protection requirements for the aeronautical mobile telemetry systems and the sharing feasibility with the (BSS(S)) and (MSS). The following paragraphs provide a summary of the activities in ITU Bureau of Radiocommunications (BR) Working Parties (WP) and Task Groups (TG) concerning sharing of these services in these bands, starting with the meetings held in the Fall of 1993.

WP/8B is the cognizant group for developing protection criteria for aeronautical mobile telemtry systems. A Preliminary Draft New Recommendation entitled "Coordination Thresholds and Techniques for the Protection of Mobile Aeronautical Telemetry Systems in the Band 1452-1525 MHz" was developed at the last WP/8B meeting and is included herein as Attachment A. Coordination threshold values are proposed in terms of Power Flux Densities (PFD) at the telemetry receiving sites as a function of angle of arrival. The Annex to this document contains the details of the development of these thresholds along with some techniques which are useful for coordination. A list of most of the telemetry receiving sites in the USA is also included in the Annex. This document was forwarded via liaison statements to: 1) TG 2-2 (formerly TG 12-4) which is the cognizant activity for developing sharing criteria with respect to the aeronautical mobile telemetry systems and the (BSS(S)), 2) WP/8D which is the cognizant activity for the (MSS), and 3), WP/10-11S which is the cognizant activity for the (BSS(S)). These liaison statement are contained in Attachment B.

TG 2-2 met in January/February 1994 in which the sharing situation between the aeronautical mobile telemetry systems and the (BSS(S)) was addressed. Results of this meeting are contained in Attachment C. Attachment C includes the Report of the sub-working group addressing this item, a Framework for a Preliminary Draft New Recommendation, and a liaison statement to WP/8B. A significant tentative conclusion is that co-frequency, cocoverage sharing of these services may not be feasible. It is also noted that co-frequency, non cocoverage operation may be very limited when a geostationary (BSS(S)) satellite is in view of an aeronautical mobile telemetry receiving station. In this respect WP/8B is requested to review the analysis of the protection requirements for the aeronautical mobile telemetry systems with the view of increasing the coordination trigger levels and increasing the feasibility of co-frequency, non cocoverage sharing.

Another Task Group, TG 8-3, was formed by Study Group 8 in April 1994, which is to address sharing situations which involve WP's and TG's within Study Group 8. This TG can consider the sharing situation between aeronautical mobile telemetry systems and the (MSS) in Region 2. The first meeting will take place in the latter part of July 1994. It is noted that this sharing situation is very similar to that with the (BSS(S)). The USA is submitting a document which indicates the nature of the additional analyses which it intends to perform with respect to the request by TG 2-2 noted above. This document is contained in Attachment D.

Another aspect of sharing among these services is the interference to earth stations in the (BSS(S)),(BS(S)) and the (MSS) services from the aircraft telemetry emissions. Attachment E contains an analysis of the PFD at the Earth's surface as a function of range, power and angle of arrival. It is also tentatively concluded that co-frequency, cocoverage operation does not appear feasible. In this case the coverage area is that which is in view of the aircraft, about 500Km for a surface based receiver. This USA document is also being submitted to TG 8-3 and subsequent TG and WP meetings in the Fall of 1994. This document is also of interest to WP 10/B, the cognizant group for the (BS(S)) in the 1452-1492 MHz band.

ATTACHMENT A

INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION
STUDY GROUPS

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PRELIMINARY DRAFT NEW RECOMMENDATION

COORDINATION THRESHOLDS AND TECHNIQUES FOR THE PROTECTION OF MOBILE AERONAUTICAL TELEMETRY SYSTEMS IN THE BAND 1 452 - 1 525 MHZ

(Resolution 528, 46 and WARC-92)

(Question 62/8)

The ITU-R,

considering

a) that in Region 2 and some Regions 1 and 3 countries the band 1 452 - 1 525 MHz is specifically allocated to the aeronautical-mobile telemetry service on a primary basis by Nos. 723, 723B and 722C;

b) that at WARC-92 the band 1 452 - 1 492 MHz was allocated to the broadcasting satellite service and the broadcasting service, subject to the provision of Nos. 722A, 722B and 722C;

c) that at WARC-92 the band 1 492 - 1 525 MHz was allocated to the mobile-satellite service (space-to-Earth) in Region 2 taking account of the provisions of No. 723C;

d) that the aeronautical-mobile telemetry service requires interference protection from the services identified in b) and c) in the indicated frequency bands;

e) that there are no coordination thresholds that apply with respect to protection of the aeronautical-mobile telemetry service in these bands;

f) that coordination is required under Resolutions 46 and 528;

g) that Resolutions 528 and 213 invite the RS to conduct the necessary studies prior to the next (appropriate) World Radio Conference (WRC),

recommends

1. that the coordination thresholds given in 1.1 and 1.2 for the protection of the aeronautical-mobile telemetry service in the 1 452 - 1 525 MHz band be applied to determine the need for coordination between administrations using the broadcasting-satellite and mobile-satellite services and administrations using the aeronautical-mobile telemetry service;

1.1 for a non-geostationary satellite with a circular orbit and an altitude in the range of 500 - 2 000 km that will be visible to any aeronautical telemetry receiving station, the coordination threshold corresponds to a power-flux density at the telemetry receiving station in any 4 kHz band for all angles of arrival and methods of modulation of:

-162.6 dB(W/m^2)

1.2 for a geostationary satellite that will be visible to any aeronautical telemetry receiving station, the coordination threshold corresponds to a power-flux density at the telemetry receiving station in any 4-kHz band for all methods of modulation of:

-186.1	$dB(W/m^2)$ for $0 \leq \alpha \leq 3.4^\circ$
$-198.4 + 23.1 \log\alpha$	$dB(W/m^2)$ for $3.4^\circ < \alpha \leq 20^\circ$
$-182.0 + 10.5 \log\alpha$	$dB(W/m^2)$ for $20^\circ < \alpha \leq 30^\circ$
$-182.0 + 10.5 \log\alpha + 10 \log [1 + 0.066(\alpha-30)]$	$dB(W/m^2)$ for $30^\circ < \alpha \leq 62.5^\circ$
$-157.1 + 20 \log (\sin\alpha)$	$dB(W/m^2)$ for $62.5^\circ < \alpha \leq 90^\circ$

where α is the angle of arrival (degrees above the horizon);

2. that the calculation methods and coordination techniques given in Annex 1 should be used, as applicable, for determining interference to the aeronautical-mobile telemetry service during coordination.

Note 1 - §§ 2 through 7 of Annex 1 provide the detailed development of the coordination thresholds given in **recommends** 1.

ANNEX 1

Coordination thresholds and techniques for the protection of mobile aeronautical telemetry systems in the band 1 452 - 1 525 MHz

1. Introduction

At the WARC-92, the band 1 452 - 1 492 MHz was allocated to the broadcasting-satellite service and the broadcasting service and, under the provisions of No. 722A is limited to digital audio and subject to Resolution 528. The band 1 492 - 1 525 MHz was allocated to the mobile-satellite service (space-to-Earth) in Region 2, subject to the provisions of No. 723C. A coordination threshold was provisionally applied which corresponds to the power-flux density (pfd) limits given in No. 2566 with respect to terrestrial services, except for the situation referred to in No. 723. For this case, the procedures of Resolution 46 apply.

Under Radio Regulations 723 and 723B, mobile-aeronautical telemetry has a primary allocation in a number of nations. No pfd limits apply to the use of these bands for this purpose, and coordination is required in these cases under Resolutions 46 and 528. Resolutions 528 and 213 invite the CCIR to conduct the necessary studies prior to the next (appropriate) World Radio Conference (WRC).

The analyses and results given in the following sections of this document are for the purpose of developing coordination thresholds, methods for calculating interference, and techniques for reducing interference to mobile-aeronautical telemetry systems (MAT).

2. Telemetry system characteristics

2.1 General

General system characteristics are given in [1] and are as follows. Aeronautical telemetry and telecommand operations are used for flight testing of manned and unmanned aerospace vehicles. Vehicles are tested to their design limits, thus making safety of flight dependent on the reliability of information received on a real-time basis. When being tested to design limits, signal strength loss can exceed 30 dB due to nulls in the aircraft antenna pattern caused by aircraft attitude changes.

- Required C/N	9-15 dB
- Transmitter Power	2-25 W
- Modulation Type	PCM/FM
- Transmission Path Length	up to 320 km
- Receiving System Noise Temp.	200-500 K
- Receiving Antenna Gain	20-41 dB

Receive antenna first side-lobe levels for two antennas

- 10 m (diameter)	20 dBi (antenna gain), 2.4° (from centre)
- 2.44 m (diameter)	7-14 dBi (antenna gain), 10° (from centre)

A number of antenna diameters are employed between the 20-41 dB limits. Left-hand and right-hand circular, as well as linear polarizations, are used.

Channel assignments are made in 1 MHz increments. Typical emissions are 1, 3, and 5 MHz in bandwidth with wider assignments made for video and other complex measurements.

The maximum air space for a telemetry receiving site is defined as a cylinder with a horizontal radius of 320 km around the site, with the lower bound determined by visibility and the upper bound determined by an altitude of 20 km. The minimum air space for a particular mission is defined as a vertical cylinder with a radius of 20 km within the maximum air space with the same lower and upper bounds as for the maximum air space.

Continuous RF tracking is employed using both monopulse and conical scan techniques.

There is no international agreement on required performance objectives for MAT. However, administrations may agree to mutually acceptable protection in bilateral coordination.

2.2 Telemetry receiving antennas

Two antenna diameters are given a 2.44 metre and a 10 metre diameter. Fig. 1 shows measured gain values for three 2.44-metre antennas and the functions used to describe the gain envelope:

$$G(\theta) = 29 + 20 \log (\sin 0.476\theta / 0.476\theta) \quad ; 0 \leq \theta \leq 5.57° \text{ (dBi)} \qquad (1a)$$

$$G(\theta) = 14 \quad ; 5.57° < \theta \leq 12.17° \text{ (dBi)} \qquad (1b)$$

$$G(\theta) = 41.13 - 25 \log \theta \quad ; 12.17° < \theta \leq 48° \text{ (dBi)} \qquad (1c)$$

$$G(\theta) = -0.901 \quad ; 48° < \theta \leq 180° \text{ (dBi)} \qquad (1d)$$

where (θ) is the off-axis angle in degrees.

Similarly, for the 10-metre antenna:

$$G(\theta) = 41.2 + 20 \log (\sin 1.97\theta / 1.97\theta) \quad ; 0 \leq \theta \leq 1.4655° \text{ (dBi)} \qquad (2a)$$

$$G(\theta) = 20 \quad ; 1.4655° < \theta \leq 3.98° \text{ (dBi)} \qquad (2b)$$

$$G(\theta) = 35 - 25 \log \theta \quad ; 3.98° < \theta \leq 48° \text{ (dBi)} \qquad (2c)$$

$$G(\theta) = -7 \quad ; 48° < \theta \leq 180° \text{ (dBi)} \qquad (2d)$$

The main lobe and first side-lobe gains are based on measured data. Equations (1c), (1d), (2c) and (2d) are based on Annex III to Appendix 29 of the Radio Regulations. These functions are shown in Fig. 2.

2.3 Telemetry transmitting antennas

The telemetry transmitting antennas are mounted on airborne vehicles and, ideally, would be isotropic radiators to cover all possible radiation angles toward the telemetry receiving station. However, in practice, multiple reflections and blockage from the airborne vehicles cause large variations in the gain pattern. Multiple reflections generally result in a Rayleigh fading distribution, and measured gain functions have shown that this is the case as shown in Fig. 3. Using Fig. 3 for a near worst case, including propagation effects, the probability (portion of time) (P_1) that a given gain (G_1) is not exceeded can be expressed as:

$$P_1 (G \leq G_1) = 1 - e^{-3.46 G_1} \text{ (numerical)} \qquad (3)$$

Distributions corresponding to an exponent of ($-5G_1$) are observed.

The received carrier-to-noise ratio (C/N) and carrier power (C) at output of the telemetry receiving antenna are proportional to this function.

3. Interference from non-geostationary satellites

3.1 Time-gain function of interference

First, some assumptions are made with respect to the non-geostationary satellite system:

1) that the system is composed of a number of satellites and that a telemetry receiving station is within the coverage area of the system;
2) that the satellite orbits are nearly circular;
3) that at least one satellite will be transmitting and be in view of the telemetry receiving station at all times, i.e., the satellite system provides continuous availability in its coverage area;
4) that the satellite ground tracks appear to be nearly uniformly distributed over the horizon plane of the telemetry receiving station;

Based on these assumptions, it is postulated that the probability density of one satellite appearing as if it were on the hemisphere of visibility of the telemetry receiving station is uniform (see Fig. 4). The actual visibility is a portion of a sphere with its centre of the Earth's centre. While this is an approximation, it is considered to be sufficiently accurate for the purposes intended. Intrinsic to this assumption is a uniform elevation angle (α) probability density function and a uniform azimuth density function. The density functions of the approximation as compared to the actual are about equal for low angles of arrival and lower for high angles of arrival. At low elevation angles, interference contributions are less because the high side lobes (and main lobe at very low angles) are shielded by the Earth. For higher satellite altitudes the error decreases, and at geostationary altitude there is little error.

The telemetry antenna is pointed at its zenith which maximizes the side-lobe contributions.

From this approximation, the cumulative probability (P_2) that the satellite is within a radius of (θ) radians, as viewed from the telemetry receiving station, is:

$$P_2 = (2 \sin(\theta/2))^2 / 2 \; ; \; 0 \leq \theta \leq \pi/2 \qquad (4a)$$

where (θ) is in radians. When $\theta << 1$:

$$P_2 = \theta^2 / 2 \qquad (4b)$$

The (θ) in equations (1) and (2) is the same as in equation (4), except for the degree-radian conversion. Thus, by combining equations (1) and (2) with (4), functions can be developed which relate the probability (portion of time) that the telemetry receiving antenna gain (G) toward the satellite is equal to or greater than a given value (G_2) as shown in Fig. 5.

Since the randomness is due to the satellite location, any randomness of the telemetry receiving antenna pointing is not significant since it is confined to the same 2π steradians as the satellite.

The received interference-to-noise ratio (I/N) and the interference power (I) are proportional to the functions shown in Fig. 5.

3.2 C/I analysis

Since equation (3) is proportional to carrier power (C) and the functions in Fig. 5 are proportional to interference power (I), the probability of C/I can be determined and is proportional to:

$$P\left((C/I) \geq (C/I)_c\right) \propto \left[\left(P_1 \left(G' \leq G_1\right)\right) / \left(P_2 \left(G'' \leq G_2\right)\right)\right] \qquad (5)$$

where $(C/I)_c$ is a chosen value.

The brackets indicate the joint, cumulative probability function. The (C) and (I) functions are independent since they result from independent sources. The indicated integration was performed and expressed as:

$$P_3 \left(\Delta G \geq G_2/G_1\right) = \left[\left(P_2 \left(G'' \geq G_2\right)\right) / \left(P_1 \left(G' \leq G_1\right)\right)\right] \qquad (6)$$

The results of this integration are closely approximated by:

$$\Delta G = [3.367/P(\Delta G)]^{1.169} \quad ; 0.0005 \leq P(\Delta G) \leq 0.05 \text{ (2.44 m antenna)} \qquad (7)$$

$$\Delta G = [1.091/P(\Delta G)]^{1.211} \quad ; 0.0005 \leq P(\Delta G) \leq 0.05 \text{ (10 m antenna)} \qquad (8)$$

This corresponds to availabilities of 95% to 99.95%.

The (C/I) in equation (5) is normally expressed in relation to (C/N), and since loss of availability is the prime concern, it is expressed in relation to the threshold $(C/N)_T$ as follows:

$$(C/I) \geq (C/N)_T \, (P_4/P_3) \qquad (9)$$

where (P_4) is the probability associated with $(C/N)_T$ and is set equal to $P(\Delta G)$ and P_3 is the probability associated with (C/I). The ratio (P_3/P_4) is analogous and numerically equal to (I/N) criteria. The allowable non-availability (P) is based on (C/(N+I)) so that $P(\Delta G) = P\text{-}P_3$ which results in:

$$P(\Delta G) = P/(I/N+1) \qquad (10)$$

It is now necessary to relate (ΔG) to pfd. First, a pfd is determined when the telemetry antenna is directed toward the satellite:

$$\text{pfd} \leq \frac{KTB\,(I/N)}{(\lambda^2/4\pi)\,G_o} \text{ (watts/m}^2\text{/B)} \qquad (11)$$

where:

K = Boltsman's Constant

B = Bandwidth-Hz

T = Noise Temperature-K°

G_o = 13183 (41.2 dB) for 10m and G_o = 794.3 (29 dB) for 2.44m.

This pfd is associated with a $(\Delta G)_m$ at a $P(\Delta G)$. At (G_o), only C is variable and thus, (C/I) is a Rayleigh function. The $(\Delta G)_m$ functions are closely approximated by

$$(\Delta G)_m = 45000/P(\Delta G) \quad ; 0.0005 \leq P(\Delta G) \leq 0.05 \text{ (10 m antenna)} \qquad (12)$$

$$(\Delta G)_m = 2710/P(\Delta G) \quad ; 0.0005 \leq P(\Delta G) \leq 0.05 \text{ (2.44 m antenna)} \qquad (13)$$

The pfd from equation (11) can be increased by $(\Delta G)m/(\Delta G)$. Thus:

$$\text{pfd} \leq \frac{KTB\,(I/N)}{G_o\,(\lambda^2/4\pi)} \cdot \frac{(\Delta G)m}{(\Delta G)} \quad ; P(\Delta G)_m = P(\Delta G) \text{ (watts/m}^2\text{/B)} \qquad (14)$$

And using equations (7) and (8) and (12) and (13) with (14) result in aggregate fds of:

$$\text{pfd} \leq \frac{0.825\ \text{KTB (I/N)}}{(\lambda^2/4\pi)} (P(\Delta G))^{0.169}\ (\text{watts/m}^2/\text{B})\ (2.44\text{m antenna}) \quad (15)$$

$$\text{pfd} \leq \frac{3.072\ \text{KTB (I/N)}}{(\lambda^2/4\pi)} (P(\Delta G))^{0.211}\ (\text{watts/m}^2/\text{B})\ (10\text{m antenna}) \quad (16)$$

It is noted that the pfd is not significantly affected by the value of P(ΔG); e.g., over a 100 to 1 range of P(ΔG), the range of pfd is 2.6 to 1 for the 10 m antenna and 2.2 to 1 for the 2.44 m antenna.

3.3 pfd versus angle of arrival

The above expressions for pfd apply for any angle of arrival. Unlike the case for the fixed service, where the antennas are pointed near the horizon, the telemetry antenna may be pointed at any elevation angle and, thus, all angles of arrival must be considered.

The second term of equation (14) represents the ratio of the worst case to the statistical case and has values from approximately 26 dB to approximately 39 dB over the range of interest of P(ΔG) and the antenna diameters. Thus, it is evident that the interference is due to side-lobe and back lobe contributions, i.e., the probability of a deep fade occurring in a main lobe conjunction is exceedingly small.

The effect of introducing an escalation of pfd with angle of arrival may be estimated as follows. With the previous assumption of a uniform probability over a hemisphere, the probability density function versus elevation angle of arrival (α) is uniform. This is modified by multiplying it by an escalation factor (pfde) which is equal to a $f(\alpha)$. A (pfde) is applied to the pfd computed without an escalation. The value of (pfde) is

$$pfd_e = \frac{f(\alpha)}{2\pi\int_o^{\pi/2} f(\alpha)} \quad (17)$$

Many LEO satellites have antenna patterns that maximize the gain toward the horizon; i.e., attempt to provide uniform pfd over the coverage area in which escalation in accordance with the elevation angle probability density function can be used. The optimum escalation tends to be unique for each LEO system and, thus, a general (pfd_e) for all cases may not be feasible.

3.4 Multiple entries

For non-geostationary orbit systems, both FDMA and CDMA methods have been proposed. CDMA represents the case where the number of multiple power entries, i.e., in the same 4 kHz, is most likely to be the highest.

The number of entries can be composed of two parts - those within a system and those from (N) systems. Generally, more than one entry (satellite) per system is expected. A number of CDMA systems have been proposed as sharing the same band.

In order to estimate the effect of multiple entries, it is assumed that independent systems have satellites whose positions are statistically independent. With this assumption, equation (6) is convolved with itself resulting in a P(ΔG) for two systems. Convolving the P(ΔG) for two systems results in a P(ΔG) for four systems, and so forth. The results of these computations for both antenna diameters can be closely approximated by a factor (F);

$$F = N^{1.325}\,[P(\Delta G)]^{0.086};\ 1 \leq N \leq 16 \quad (18)$$

where: N - number of equivalent equal level entries and $0.0005 \leq P(\Delta G) \leq 0.05$.

Again, it is noted that the value of (F) is not significantly affected by the value of P(ΔG) over the range of P(ΔG). To evaluate the single entry pfd, the value of equation (18) is used in the denominator of equations (15) and (16).

4. Impact on telemetry link design

The previous analyses show that the value of (P), the telemetry link non-availability, does not significantly affect the pfd values. The pfd values are primarily determined by the value of I/N. The impact on the telemetry link measured in terms of the decrease in usable range (R) for a given (P), as a function of (I/N) can be determined from equation (10), since $R^2 \propto 1/(N+I)$ for a fixed transmitter power. The decreased usable range as a function of (I/N) is shown in Fig. 6. The impact on telemetry link design becomes severe for (I/N) values greater than one (0 dB) because the link must be designed to overcome interference rather than internal noise. The maximum practical value is considered to be approximately 0.5 (-3 dB) with smaller values desired.

5. Interference allowances

Based on the factors given in § 4.0, the following aggregate allowances appear appropriate for this case. The total "noise" is the sum of internal noise (N_I) plus interference from satellites (I_S) plus interference from terrestrial sources (I_T). The aggregate permissible interference from satellites and terrestrial sources are:

$$I_S = 0.25\ (N_I + I_S + I_T) \tag{19}$$

$$I_T = 0.10\ (N_I + I_S + I_T) \tag{20}$$

From this, the aggregate allowable (I/N) from satellites is 0.3846 or -4.15 dB, and from terrestrial sources is 0.1538 or -8.13 dB. Since pfd is not particularly sensitive to (P), a mid range value of (P) of 0.005 is selected for numerical evaluation which results in a P(ΔG) of 0.003611 from equation (10).

6. Interference from geostationary satellites

6.1 Time-gain function of interference

In the case of a geostationary satellite, the angle-of-arrival of interference at a telemetry receiving station is fixed. The only randomness involved is the telemetry receiving antenna pointing variations. Testing of airborne vehicles is often restricted to areas over water or uninhabited land in order to preclude danger to life or property in case of catastrophic failure of the vehicle being tested, thereby limiting the azimuth angles for these tests. There are also minimum limits on the azimuth and elevation pointing angle variations of the telemetry receiving antenna that are defined by the minimum air space in § 2.1.

6.2 C/I analyses

In order to estimate the probabilities when the satellite is within the limited range of the main lobe pointing variation of the telemetry receiving antenna, the analyses of § 3.2 are repeated for limited ranges of equations (1) and (2).

The results of these analyses are closely approximated by the following expression.

$$\Delta G = [K/P(\Delta G)]^{1/x} \tag{21a}$$

For the 2.44 m antenna:

$x = 1.0035 - 0.0546S^{0.542}$; $0.00628 \leq S \leq 6.28$

$K = 28.41/(S^{1.16} + 0.00769)$; $0.00628 \leq S \leq 6.28$

$\Delta G = (\Delta G)_m = 2710/P(\Delta G)$; $0.0005 \leq P(\Delta G) \leq 0.05$

For the 10m antenna:

$x = 1.03 - 0.1395S^{0.208}$; $0.000628 \leq S \leq 6.28$

$K = 10.03/(S^{1.21} + 0.0000905)$; $0.000628 \leq S \leq 6.28$

$\Delta G = (\Delta G)_m = 45000/P(\Delta G)$; $0.0005 \leq P(\Delta G) \leq 0.05$

where S-telemetry antenna pointing area limit-steradians.

An approximate composite function for (ΔG) at a $P(\Delta G) = 0.003611$ is:

$$\Delta G = 8262/S^{0.915} \qquad ; 0.000628 \leq S \leq 6.28 \qquad \text{(21b)}$$

6.3 Minimum (S) versus angle of arrival (α)

The minimum value of (S) can be determined from the minimum radius of a circle in which aircraft testing is normally accomplished (see Fig. 7). (S) as a function of (α) is determined as follows. The elevation angle of arrival is:

$$\alpha = \tan^{-1}\left[\frac{h}{d} - \frac{d}{2r}\right] \qquad \text{(radians)} \qquad (22)$$

The incremental angle of arrival ($\Delta\alpha$) along the telemetry antenna pointing azimuth is:

$$\Delta\alpha = \tan^{-1}\left[\frac{h}{d-2a} - \frac{d-2a}{2r}\right] - \tan^{-1}\left[\frac{h}{d} - \frac{d}{2r}\right] \qquad \text{(radians)} \qquad (23)$$

The angle tangent to the azimuth (β) is:

$$\beta = 2\tan^{-1}\left[\frac{a}{d-a}\right] \qquad \text{(radians)} \qquad (24)$$

from which (S) is:

$$S = \pi/4\ (\beta)\ (\Delta\alpha) \qquad \text{(steradians)} \qquad (25)$$

where:

h - aircraft altitude - 20 km

d - surface distance to aircraft (320 km maximum)

r - radius of the earth - 6376 km

a - minimum radius of flight patterns - 20 km

The results of the calculations using the above equations for the 10 m antenna are closely approximated by:

$$S = 0.001262 \qquad ; 0 \leq \alpha \leq 0.059337\ (3.4°) \qquad \text{(26a)}$$

$$S = 1.557\ \alpha^{2.52} \qquad ; 0.059337 \leq \alpha \leq 1.09075\ (62.5°) \qquad \text{(26b)}$$

$$S = 1.9380 \qquad ; 1.09075 \leq \alpha \leq 1.571\ (90°) \qquad \text{(26c)}$$

and for the 2.44m antenna:

$S = 0.00628$	; $0 \le \alpha \le 0.11217$ (6.43°)	(27a)
$S = 1.557\ \alpha^{2.52}$	; $0.11217 \le \alpha \le 1.09075$ (62.5°)	(27b)
$S = 1.9380$	; $1.09075 \le \alpha \le 1.571$ (90°)	(27c)

Equation (26) is the composite of (26) and (27).

6.4 pfd versus angle of arrival

6.4.1 pfd escalation due to (S)

The permissible pfd increases with (S) which increases with angle of arrival (α). The pfd as a function of (S) can be calculated using equations (26) and (27) in equation (21a) or (21b) with $P(\Delta G) = 0.003611$ which, in turn, are used in equation (14). However, to be used as a pfd escalation (pfd_{e1}), the calculated values of pfd are normalized to the pfd for a 10m antenna with an (S) = 0.001262 (see equation 26a). The functions for the two antenna diameters are shown in Fig. 8. The worst case composite of the two functions is closely approximately by:

$pfd_{e1} = 1$	; $0 \le \alpha \le 3.4°$	(28a)
$pfd_{e1} = 0.0592\ \alpha^{2.31}$	; $3.4° \le \alpha \le 62.5°$	(28b)
$pfd_{e1} = 833.2$	; $62.5° \le \alpha \le 90°$	(28c)

6.4.2 pfd escalation due to excess margin

There will be some distance (d_o) between the telemetry receiving station and the airborne vehicle at which the desired availability is generally exceeded. Thus, excess margin is available which could be used to increase the allowable pfd. The value of (d_o) can be determined by:

$$d_o = \left[\frac{P G_a G_o}{1758\ KTBM\ f^2\ (C/N)_T} \right]^{0.5} \text{(km)} \qquad (29)$$

where

P	- aircraft power-watts	4
G_a	- aircraft median antenna gain	0.2
G_o	- telemetry receiving antenna gain	800
M	- availability margin required	300
f	- frequency - MHz	1 500
T	- noise temperature - K°	250
B	- bandwidth - Hz	3×10^6
$(C/N)_T$	- threshold value	32

The nominal values for each parameter as listed above are considered to be the most appropriate for determining (d_o). Solution of equation (29) with these values result in a (d_o) of 40 km (see Fig. 9).

The angle of arrival (α) is determined by the distance (d) and the aircraft height (h) and is:

$$\alpha = \arcsin (h/d) \qquad (30)$$

From equation (30), (α) as a function of (d) for values of (d) between (d_o) and (h) can be determined. The excess margin (M_e) which can be used to increase the pfd is:

$$M_e = (d_o/d)^2 \quad (31)$$

The maximum value of (h) is assumed to be 20 km. Using these values (M_e) as a function of (α) is computed. A nearly exact formulation of this function can be expressed as a pfd escalation factor (pfd_{e2}) as follows:

$$pfd_{e2} = 1 \quad ; 0 \leq \alpha \leq 30° \quad (32a)$$

$$pfd_{e2} = 1 + 0.066\,(\alpha - 30) \quad ; 30° < \alpha \leq 62.5° \quad (32b)$$

$$pfd_{e2} = 4 \sin^2\alpha \quad ; 62.5° < \alpha \leq 90° \quad (32c)$$

6.4.3 Aggregate pfd_e versus angle of arrival (α)

The aggregate escalation (pfd_{ea}) versus the elevation angle of arrival is the product of the functions given in paragraphs 6.4.1 and 6.4.2 and is:

$$pfd_{ea} = 1 \quad ; 0 \leq \alpha \leq 3.4° \quad (33a)$$

$$pfd_{ea} = 0.0592\,\alpha^{2.31} \quad ; 3.4° \leq \alpha \leq 30° \quad (33b)$$

$$pfd_{ea} = 0.0592\alpha^{2.31}\,(1+0.066(\alpha-30)) \quad ; 30° \leq \alpha \leq 62.5° \quad (33c)$$

$$pfd_{ea} = 3{,}332\,(\sin\alpha)^2 \quad ; 62.5° \leq \alpha \leq 90° \quad (33d)$$

6.5 Multiple entries

When the value of (S) is very small, side and back lobe interference levels from similar satellites in the (GSO) will be insignificant as compared to the main lobe level. As (S) increases, the side and back lobe contributions become statistically significant and are accounted for on a per-satellite basis in § 6.2. Therefore, multiple entries are primarily related to the number of geostationary satellites within the limited steradian coverage of the telemetry antenna (S).

First, it is assumed that an area (S′) is circular and that its diameter (δ) is aligned with the GSO, and second, it is assumed that there are (N) satellites equally spaced by an angle (Δ), each producing equal pfds at the telemetry antenna.

When (δ) is equal to (Δ), two entries are possible but the probability is near 0. When (δ) is equal to (2Δ), the probability of two entries is near 1, while probability of three entries is near 0, and so forth. Thus, for a probability of about 0.5:

$$\delta = (N-0.5)\Delta; \ \delta \text{ and } \Delta \text{ in degrees} \quad (34)$$

The area (S′) is:

$$S' = (\pi/4)\,\delta^2 \text{ (steradians); } \delta\text{- radians} \quad (35a)$$

$$S' = 0.00023921\,\delta^2 \text{ (steradians); } \delta\text{- degrees} \quad (35b)$$

From this model, (N) is closely approximated by:

$$N = 70(S')^{0.5}/\Delta; \ \Delta^2/4900 \leq S \leq 1.938 \quad (36)$$

Since $N \geq 1$, $S' \geq \Delta^2/4900$, and since the "maximum" minimum value of (S) from paragraph 6.3 is 1.938, (N) in equation (36) is limited to this range. Thus, (N) is limited to the range; $1 \leq N \leq (90/\Delta + 0.5)$.

By equating equation (35) to the composite of equations (26) and (27) with the limits of equation (28), the value of $(S')^{0.5}$ can be expressed in terms of the elevation angle of arrival (α); $(S')^{0.5} = 0.0076\ \alpha^{1.26}$. Substituting this in equation (36) results in:

$$N = 0.532\ \alpha^{1.26}/\Delta;\ 3.4° \leq \alpha \leq 62.5° \quad (37)$$

From this equation for N=1 and $\alpha = 3.4°$, $\Delta \geq 2.5°$ and for $\alpha = 62.5°$ and N = 1, $\Delta \leq 97.4°$. For $\Delta = 2.5°$ and $\alpha = 62.5°$, $N \leq 39$.

The single entry escalation (pfd_{es}) is related to the aggregate (pfd_{ea}) by

$$pfd_{es} = pfd_{ea}/N \quad (38)$$

7. Coordination thresholds

7.1 General

From the preceding analyses, values of aggregate and single entry pfds may be developed. When the pfd from a satellite is less than the single entry value, coordination would not be required. The pfd single entry values developed in the following sections are proposed as applicable for Mobile Aeronautical Telemetry systems. Telemetry systems parameter values common to both geostationary and non-geostationary satellites cases (LEOs) are as follows:

T - Receiving Station Noise Temperature - 250°K

B - Referenced Bandwidth - 4 kHz

λ - Wavelength - 0.2 meters

I/N - Interference/Noise - 0.3846 (see 5.0)

P(ΔG) - Probability of Differential Gain - 0.003611 (see 5.0)

7.2 Non-geostationary satellites

The pfds developed in the following paragraphs apply to LEOs with circular orbits, with inclinations such that a satellite will be visible at all azimuth and elevation angles about the telemetry receiving stations, and that the satellites have altitudes that are generally in the 500 to 2 000 km range. The pfds apply for all angles of arrival.

The solution of equations (16) and (17) provides the aggregate pfd interference thresholds for the 10 m and 2.44 m antennas. The results are:

$$pfd_a \leq -148\ \text{dBW/m}^2\text{/4 kHz (10 m)} \quad (39)$$

$$pfd_a \leq -152.7\ \text{dBW/m}^2\text{/4 kHz (2.44 m)} \quad (40)$$

Thus, the limiting aggregate interference threshold is the value for the (2.44 m) antenna.

The value of (F) from equation (18) is uncertain at this time and, therefore, should be conservative. Generally, multiple coverage within an LEO system will increase with latitude, with the satellite spacing being deterministic. For purposes of developing a single entry pfds, a value of two is assumed for internal system coverage and a value of four for the number of systems resulting in N = 8 for equation (18); i.e., eight statistically independent equal level entries. This results in a single entry pds threshold of:

$$pfd_s \leq -162.6\ \text{dBW/m}^2\text{/4 kHz} \quad (41)$$

7.3 Geostationary satellites

The base value of pfd, from which the escalation factors given in § 6.4 are applied, is determined by equation (14) with $G_0 = 13183$ and the ratio $(\Delta G)m/(\Delta G)$ determined by equation (12) and equation (21) for the 10m antenna with a value of (S) equal to 0.001262 from equation (26a). This results in a value of -186.1 dBW/m²/4 kHz. The escalation factors given in equation (33) are applied to this value to arrive at an aggregate interference threshold as follows:

$pfd_a \leq -186.1$; $0 \leq \alpha \leq 3.4°$ (dBW/m²/4 kHz) (42a)

$pfd_a \leq -198.4 + 23.1 \log \alpha$; $3.4° \leq \alpha \leq 30°$ (dBW/m²/4 kHz) (42b)

$pfd_a \leq -198.4 + 23.1 \log \alpha + 10 \log [1 + 0.066 (\alpha - 30)]$; $30° \leq \alpha \leq 62.5°$ (dBW/m²/4 kHz) (42c)

$pfd_a \leq -150.9 + 20 \log (\sin \alpha)$; $62.5° \leq \alpha \leq 90°$ (dBW/m²/4 kHz) (42d)

The value of (Δ) in equation (37) is uncertain at this time and, therefore, should be conservative. A value of about 25° is chosen; a value of 23.2° is convenient in that (N) = 1 at (α) = 20° in equation (37). Given this value of (Δ), the value of (N) is applied to pfd_a as in equation (38) to arrive at a single entry (pfd_s) coordination threshold:

$pfd_s \leq -186.1$; $0 \leq \alpha \leq 3.4°$ (dBW/m²/4 kHz) (43a)

$pfd_s \leq -198.4 + 23.1 \log \alpha$; $3.4° \leq \alpha \leq 20°$ (dBW/m²/4 kHz) (43b)

$pfd_s \leq -182.0 + 10.5 \log \alpha$; $20° \leq \alpha \leq 30°$ (dBW/m²/4 kHz) (43c)

$pfd_s \leq -182.0 + 10.5 \log \alpha + 10 \log [1 + 0.066 (\alpha - 30)]$; $30° \leq \alpha \leq 62.5°$ (dBW/m²/4 kHz) (43d)

$pfd_s \leq -157.1 + 20 \log (\sin \alpha)$; $62.5° \leq \alpha \leq 90°$ (dBW/m²/4 kHz) (43e)

The aggregate and single entry interference thresholds are plotted in Fig. 10 as a function of elevation angle of arrival (α).

8. Coordination considerations for satellite interference to aeronautical telemetry systems

8.1 General

When the coordination thresholds are exceeded, coordination with the affected Aeronautical Telemetry systems would be required. There are a number of factors and techniques by which successful coordination may be achieved. Some of the applicable factors and techniques that apply to Aeronautical Telemetry systems are addressed in the following paragraphs.

8.2 Considerations applying to LEO and GEO satellites and all telemetry receiving sites

8.2.1 Telemetry carrier bandwidth

Power-flux densities are commonly expressed in a 4 kHz bandwidth at these frequencies. When the interfered-with carrier bandwidth is much larger than 4 kHz, the assumption that the highest pfd per 4 kHz exists over the interfered-with carrier bandwidth may over estimate the actual level of interference. Thus, expressing a pfd in the minimum interfered-with bandwidth that is most sensitive to interference more accurately represents the actual situation.

The minimum bandwidth most sensitive to interference is represented by an FSK carrier with a data rate of approximately 400 Kb/s. Thus, the most sensitive portions of the carrier spectrum are approximately 400 kHz, while the total RF spectrum required is nearly 1 MHz. Thus, a pfd expressed in dBW/m²/400 kHz is more appropriate.

8.2.2 Modulations

There are several types of modulations used by aeronautical telemetry systems, including both analogue and digital, with a trend toward becoming all digital. The analyses in the preceding sections have not addressed the interference effects for various combinations of interfering and interfered-with modulations. When there are a number of interfered-with modulations involved, it is generally desirable that the interfering signal appear as broadband noise. However, certain combinations of modulations could result in interference effects that are less than broadband noise.

However, the coordination thresholds are considered valid for all types of interfering modulations, noting that the broadcasting service (sound) is limited to digital systems.

8.3 Considerations applying to LEO and GEO satellites on a telemetry site basis

8.3.1 Polarizations

The aircraft antenna by itself is generally linear polarized, but the polarization leaving the aircraft will generally be elliptical with varying ellipticities and spatial orientation. As noted in § 2.1, telemetry receiving antennas use RHC, LHC, and linear polarization. For telemetry sites where all three of these polarizations are not used, some polarization isolation may be achieved. Some sites use both RHC and LHC with diversity combining. This results in a 3 dB polarization isolation from any single polarization interfering signal.

8.3.2 Frequency Avoidance

In the case of isolated telemetry site (no overlapping air space with any other site) with a relatively light testing schedule, it may be possible to avoid the use of portions of the 1 452 - 1 525 MHz band. This could allow BSS(S) or MSS operations with pfds in excess of the values developed herein for co-frequency use. In the usual case, where many overlaps occur and simultaneous testing occurs, frequency coordination between telemetry sites on a continuous basis is necessary and frequency avoidance will generally not be possible or practical.

8.3.3 Telemetry site specific parameters

For telemetry sites that have parameter values different than those used for the development of coordination thresholds, acceptable pfds may be computed using the methods and equations used in the development of the coordination thresholds. These parameters include $P(\Delta G)$, (S), (d), (h), (P), (I/N), (T), etc. as defined in the preceding analyses.

8.4 Non-geostationary (LEO) satellite system

In addition to the considerations given in §§ 8.2 and 8.3, or alternatively, the following considerations apply to LEO systems. As previously indicated, the analyses are based on near-circular orbits with altitude in the general range of 500 to 2 000 km.

First, it is noted that the (pfd_a) values given in § 7.2 are not very sensitive to (G_o), the on-axis gain of the telemetry receiving antenna; i.e., a 4.2 dB variation of (pfd_a) for a 12.2 dB variation in (G_o). Therefore, a (pfd_s) of -162.6 dBW/m^2/4 kHz or -142.6 dBW/m^2/400 kHz may be used as an average value for $(G_o)_s$ between 20 dB and 41.2 dB, to which the (pfd_e) in equation (17) can be applied. As noted in § 3.3, the "optimum" escalation (pfd_e) is dependent on the specific implementation of a LEO satellite; i.e., the expected pfd versus elevation angle of arrival (α) depends on the LEO satellite antenna gain pattern and power control, if used. Equation (17) may be expressed in a more general fashion as follows:

$$pfd_e = \frac{f(\alpha)\int_o^{\pi/2} f'(\alpha) pfd_{e2}}{\int_o^{\pi/2} f(\alpha) f'(\alpha)} \qquad (44)$$

where: f(α) - pfd versus (α) from the satellite for an overhead pass

f'(α) - Probability density function versus (α) for a uniform satellite probability over the portion of satellite sphere visible to the telemetry receiving station. This function has lower values for higher (α)s than a uniform function.

pfd_{e2} - Equation (32), which is also applicable to LEO satellites.

Solution of equation (44) should result in a near-optimum (pfd_e) function for a specific satellite implementation; i.e., most favourable from the satellite standpoint.

The conditions for equation (44) are usually met if the inclinations of the satellite orbits are considerably greater than the latitude of the telemetry receiving site. If this condition is not met, more detailed analysis may be necessary. The f' (α) becomes a function of azimuth angle from the telemetry receiving site for this case.

Another factor which can be considered is the effective number of equal level entries within a LEO system. A value of two statistically independent entries was assumed in determining the coordination threshold. This value could be appropriately modified for a particular system.

In general, detailed interference analyses for LEO systems will be unique for each system and can be complex since they involve a large number of varying parameters.

8.5 Geostationary (GEO) satellites

8.5.1 General

In addition to the considerations given in §§ 8.2 and 8.3, or alternatively, the following considerations apply to GEO satellites.

8.5.2 Satellite antenna discrimination

When the telemetry sites are outside the coverage area of the satellite, satellite antenna discrimination is a very important factor in determining the need-to-coordinate as well as in coordination.

8.5.3 The conjunction case

This is the case where the main lobe of the telemetry receiving antenna can be pointed at a geostationary satellite. For this case, interference analyses need to address each telemetry receiving site. Referring to Fig. 8, it is noted that the escalation (pfd_{e1}) for low angles of arrival for the 2.44 m antenna is based on the on-axis gain (G_o) of that antenna. This value of (pfd_{e1}) for the 2.44 m antenna can be transferred to Fig. 10. Other values of (G_o) can also be placed on Fig. 10, as shown in Fig. 11. The pfd for values of (G_o) are computed by equation (11) with the parameter values in § 7.1. Using these values:

$pfd \le -146.7 - G_o$ (dB) (dBW/m^2/4 kHz) (45a)

$pfd \le -126.7 - G_o$ (dB) (dBW/m^2/400 kHz) (45b)

for $20 \le G_o \le 38.4$.

Three parameters are needed to use this Fig.: (1) the locations of the telemetry receiving sites, (2) the maximum antenna gain at each site, and (3) the geostationary satellite location. This first step is relatively simple and may eliminate a number of sites from further consideration.

For those cases requiring further consideration, there may be some cases where the telemetry antenna does not have a conjunction with the geostationary satellite at low angles of arrival but does have a conjunction at higher angles of arrival. This could occur when the azimuth limits for testing at long ranges are such that conjunctions would not occur for low angles of arrival, but can occur at higher angles because (S) increases with (α). The minimum pfd value for this case is the value in Fig. 11 at the angle (α) where conjunctions first occur.

8.5.4 The no conjunction case

It is possible that in coordination, there are telemetry sites where the antennas can avoid a geostationary satellite by some value of solid angle which is acceptable for those sites' operations.

A first order approximation for the escalation of the aggregate pfd can be obtained from equations (1) and (2) as shown in Fig. 12. This figure also shows a composite function which covers all antenna sizes. Since the solid angle includes both azimuth and elevation, the angle of arrival escalation (pfd_{e1}) due to (S) is not additive to this function, but (pfd_{e2}) may be added in accordance with the elevation angle.

The variation of (S) can also be examined with respect to pfd and the angle of avoidance. One particular case has been addressed from a statistical standpoint; i.e., the case of the telemetry antenna main lobe avoidance (to the first side lobe level). The probabilities for this case were determined as a function of (S) as in § 6.2 for the conjunction case. The results of these analyses for the two antennas are approximated by a composite (ΔG) function (ΔG_S):

$$\Delta G_S = 1948/S^{0.363} \qquad ; 0.000628 \leq S \leq 6.28 \qquad (46)$$

A modifying factor (Δ pfd) for equation (42) can be determined by the ratio (ΔG) from equation (21b) divided by (ΔG_S) from equation (46) and substituting the value of (α) from equation (26) which results in:

$$\Delta \text{pfd} = 169.4 \qquad 0 \leq \alpha \leq 3.4°$$

$$\Delta \text{pfd} = 929.2/\alpha^{1.391} \qquad 3.4° \leq \alpha \leq 62.5° \qquad (47)$$

$$\Delta \text{pfd} = 2.95 \quad 62.5° \leq \alpha \leq 90°$$

Equation (47) does not include any allowance for multiple entries; i.e., it is applicable when only one geostationary satellite is visible to the telemetry station.

The avoidance angle is approximately 1.5° for a 10 m antenna and approximately 6° for a 2.44 m antenna. For low elevation angles (Δ pfd) is the ratio of (G_O) divided by the first side lobe level as in Fig. 9. While the value of (Δ pfd) increases with decreasing (G_O), the avoidance angle of the telemetry antenna increases with decreasing (G_O). The aggregate pfd with only the pfd_{e1} included is shown in Fig. 13 and compared with the same function with conjunctions. Main lobe avoidance, where possible, may significantly increase the allowable pfd at low angles of arrival but more detailed analyses would be needed in coordination.

9. Interference from terrestrial broadcasting

9.1 General

Sound broadcasting from terrestrial stations is also allocated in the 1 452 - 1 492 MHz band. In this case, interference to a telemetry receiving station will occur at near 0_ elevation angles and at a fixed azimuth angle for a particular broadcasting station site and telemetry site. This is similar to the geostationary satellite case.